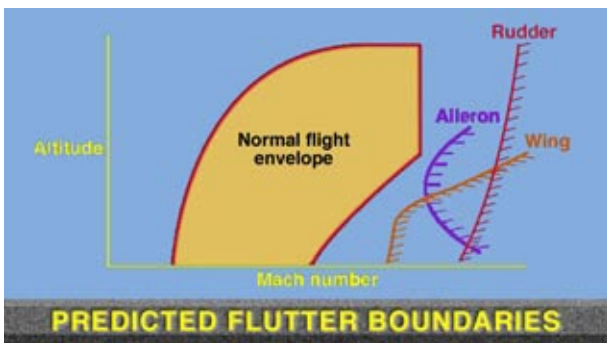


Information Summaries

IS-97/08-DFRC-F1

Flutter Excitation



Background

One of the most dangerous events that can occur in flight is a phenomena called "flutter". Flutter is an aerodynamically induced vibration of a wing, tail, or control surface that can result in total structural failure in a matter of seconds. The prediction of flutter is not a precise science and requires flight verification that flutter will not occur within the normal flight envelope.

The aerodynamic surfaces of an airplane are constructed so that they can carry the loads that are produced in flight. For example the wing must be capable of supporting the weight of the airplane as well as the additional lift produced during turning flight. The resulting wing structure can be viewed as a blade or spring extending from the fuselage. If we "tap" the spring with a hammer, it will vibrate at a frequency which relates to the stiffness of the spring. A stiff spring will vibrate at a higher frequency than a more limber spring. This frequency is known as the "natural frequency" of the spring.

Flutter will usually occur at or near the natural frequency of the structure, that is, some small aerodynamic force will cause the structure to vibrate at its natural frequency. If this small force persists at the same frequency as the natural frequency of the structure, a condition called "resonance" occurs. Under a resonant condition, the amplitude of the vibration will increase dramatically in a very short time and can cause catastrophic failure in the structure.

The aerodynamic forces which can induce flutter are related to the dynamic pressure, or airspeed, of the airplane. If flutter-inducing forces are present they will increase as the airspeed is increased. Flutter characteristics can be explored by "tapping" the surface at progressively faster airspeeds, then watching how fast the vibrations decay or damp out. The vibrations will take longer to decay as the airspeed approaches a possible resonant condition. In this way potential flutter can be approached safely without actually reaching the resonant condition and experiencing sustained flutter.

The method for "tapping" the surface varies. On some airplanes a sharp control pulse is sufficient to excite the natural frequency of the surface. In most cases a special flutter excitation device is installed. This device will

use either an aerodynamic vane or an unbalanced mass which is driven back and forth at the known natural frequency of the surface. The device is abruptly turned off and the natural damping characteristics of the vibrating surface are revealed. The analysis is similar to the frequency and damping analysis discussed under the "control pulse" maneuver, except that the structural (or flutter) frequencies are much higher.

1. Specific Objective of the Test

Determine that the airplane aerodynamic surfaces are free of flutter throughout the normal flight envelope of the airplane. Each surface will be considered free of flutter if structural vibrations damp out in a reasonable time when the surface is artificially vibrated while at the maximum airspeed of the airplane. Individual tests will be conducted on each surface which has a potential for flutter.

2. Critical Flight Conditions

Flutter response varies with the following variables:

- Airspeed
- Altitude
- Mach number

Critical flight conditions for flutter excitation testing are highly dependent on the individual airplane and not easily generalized. Caution is usually exercised in the high Mach number region or transonic region where unusual aerodynamic forces could be present.

The primary controlled variable will be airspeed. Due to the hazardous nature of flutter testing it is almost always done with full support from either ground telemetry analysis or on-board data analysis, or both. Real time analysis is necessary to assess the results from each individual excitation in order to decide whether to proceed to the next higher airspeed.

3. Required Instrumentation

The parameters usually measured and recorded during a flutter excitation test are shown in Table (1-1). Notice that this list contains some standard instrumentation necessary to identify flight conditions, and a series of specialized sensors (usually strain gages or accelerometers) located at selected remote locations on the airplane. Various "sets" of sensors are specifically designed to identify vibrations on a particular structural surface.

A continuous time history of these parameters is needed for each excitation. The structural frequencies are usually quite high (from 5 to 60 cycles per second) which dictates an extremely high sampling rate (up to 500 samples per second). As a result, these structural measurements are often handled completely separately from the other instrumentation and may be recorded on a different recorder or use a different telemetry system.

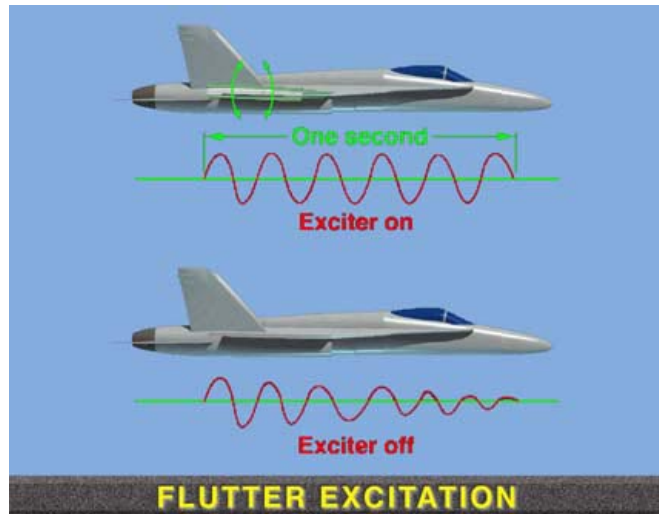
4. Starting Trim Point

A single flutter excitation test will identify the frequency and damping data for one structural surface at one flight condition of Mach number and airspeed. The flight test engineer will establish a table of flight conditions where a series of flutter excitation tests are desired. The test series will start at a moderate airspeed, well below the expected flutter boundary, in order to establish a baseline damping level for the surface. The tests will progress in small steps toward the predicted boundary, with data analysis occurring between each excitation. A different table of conditions will be assembled for specific flutter test on each aerodynamic surface. A typical sample table of flight conditions for a series of flutter excitation tests is shown in Table (1-2).

Description of a Flutter Excitation Test

The pilot will establish the airplane at the desired speed and altitude. The pilot will then trim the airplane and obtain a short "trim shot" before initiating the excitation device. In some cases the aircraft may be descending in order to stabilize on an airspeed and the excitation will start when the Mach number or altitude passes

through the desired test point. If the structure is to be excited using a flight control pulse, the pilot will rap the appropriate cockpit control, then release it. If a flutter excitation device is installed, the unit will be activated by the pilot or flight test engineer for several seconds, then abruptly turned off.



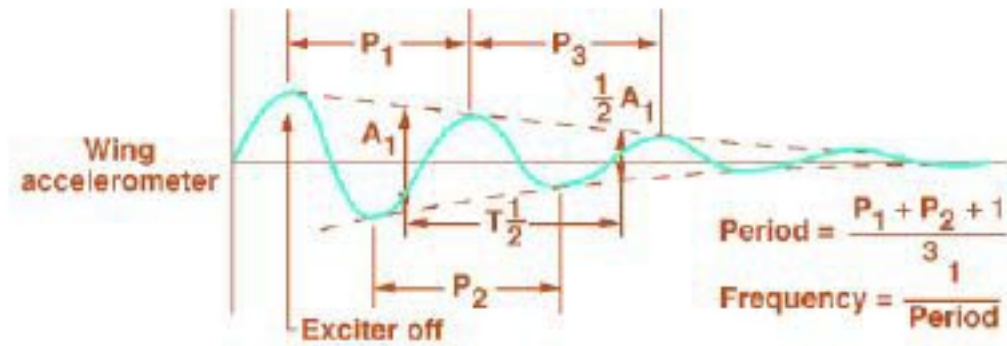
Following the test the pilot will either remain at the same test condition or decelerate slightly while the analysis of the structural damping takes place. Upon approval from the structural analysis team, the pilot will accelerate slowly to the next flight condition and stabilize for the next flutter excitation test. If the structural damping is noticeably less than the previous test point, the test series will be terminated and the airplane will land while a more detailed analysis of all measured parameters is performed.

6. Measures of Success

A successful flutter excitation test will meet the following test criteria:

- All instrumented parameters were recorded properly. Table (1-1).
- Airspeed and Mach number were stabilized at the desired condition.
- The structural mode of the surface was disturbed enough to identify frequency and damping.
- Damping of the structural mode was positive and not significantly different from previous tests at lower airspeeds.

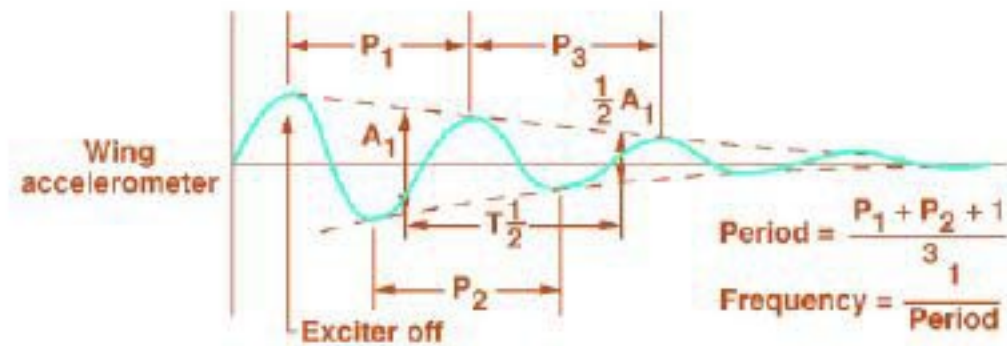
Frequency can be determined by first marking the location of the peak values for one of the oscillating measurements as shown.



FLUTTER FREQUENCY AND DAMPING

Averaging the time between the peaks on one side will produce the period of the oscillation or time for one cycle (seconds per cycle). Frequency is merely the inverse of this measurement (cycles per second).

Damping can be determined by first connecting the peaks with a smooth curve as shown.



FLUTTER FREQUENCY AND DAMPING

Measure the distance between the two enveloping curves at a time shortly after the control was released (A_1). Mark the time. Now find a later time where the distance between the two envelopes is exactly half of the first measurement ($\frac{1}{2} A_1$). Again mark the time. The time measurement between the first and second marks is the time-to-half-amplitude ($T_{1/2}$) which defines the damping of the oscillation.

It is important to understand that when a test indicates that a flutter boundary is being reached much earlier than expected, and the tests are terminated early, this is not an indication of a failed test. It indicates a successful TEST, but a failed PREDICTION.

Table 1-2

Table of Flutter Excitation Test Conditions

Config.	Alt.	Airspeed	Mach
Clean	10000	300	.54
		320	.58
		330	.595
		340	.61
	20000	300	.65
		340	.71
		350	.75
		360	.775
	30000	300	.79
		340	.885
		360	.93

Table 1-1

Listing of Instrumentation Parameter

Parameter	Used for
Air Speed	Compute Mach and dyn. pres.
Pressure Altitude	
Outside Air Temperature	
Flutter Exciter	Determine start and end of excitation
Elevator Position	Excitation devices, or review for possible flight control interaction with the structure
Aileron Position	
Rudder Position	
Wing tip accelerations	Measure structural frequency and damping
Wingstrain gages	